Assimilation of TES ozone into the GEOS-Chem and GFDL AM2 models: implications for chemistry-climate coupling

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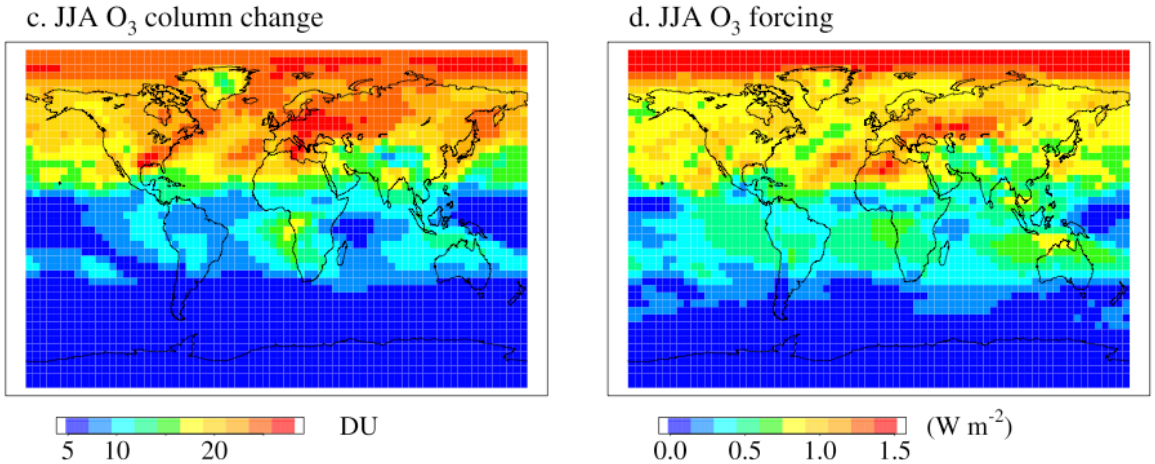
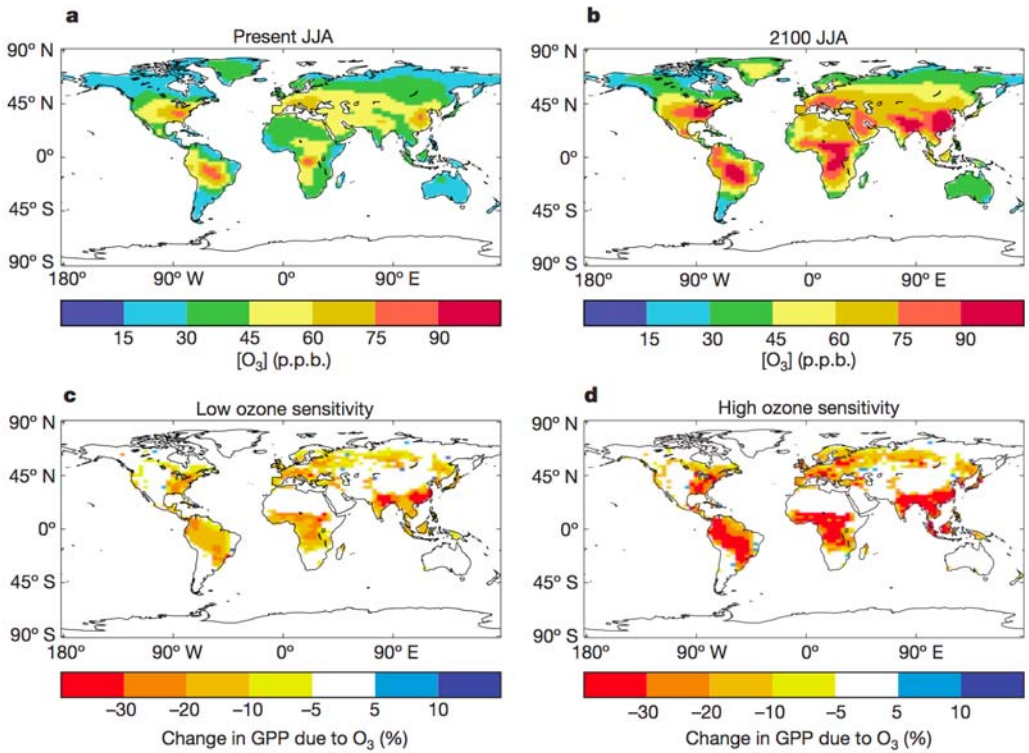
Role of ozone in chemistry-climate coupling



Mickley et al,(2004), *JGR*

Direct effect:
Instantaneous radiative forcing from tropospheric ozone since preindustrial times of .49 W/m^2

Change of .28^o C increase in global annual mean surface temperature



Indirect effects:
Suppression of carbon uptake by ozone damage to plants could lead to additional 0.62 to 1.09 W/m^2 CO_2 radiative forcing

Sitch et al,(2007), *Nature*

Observational constraints on climate prediction

How can predictions from global chemistry-climate models (GCCM) be constrained by current observations, e.g. TES?

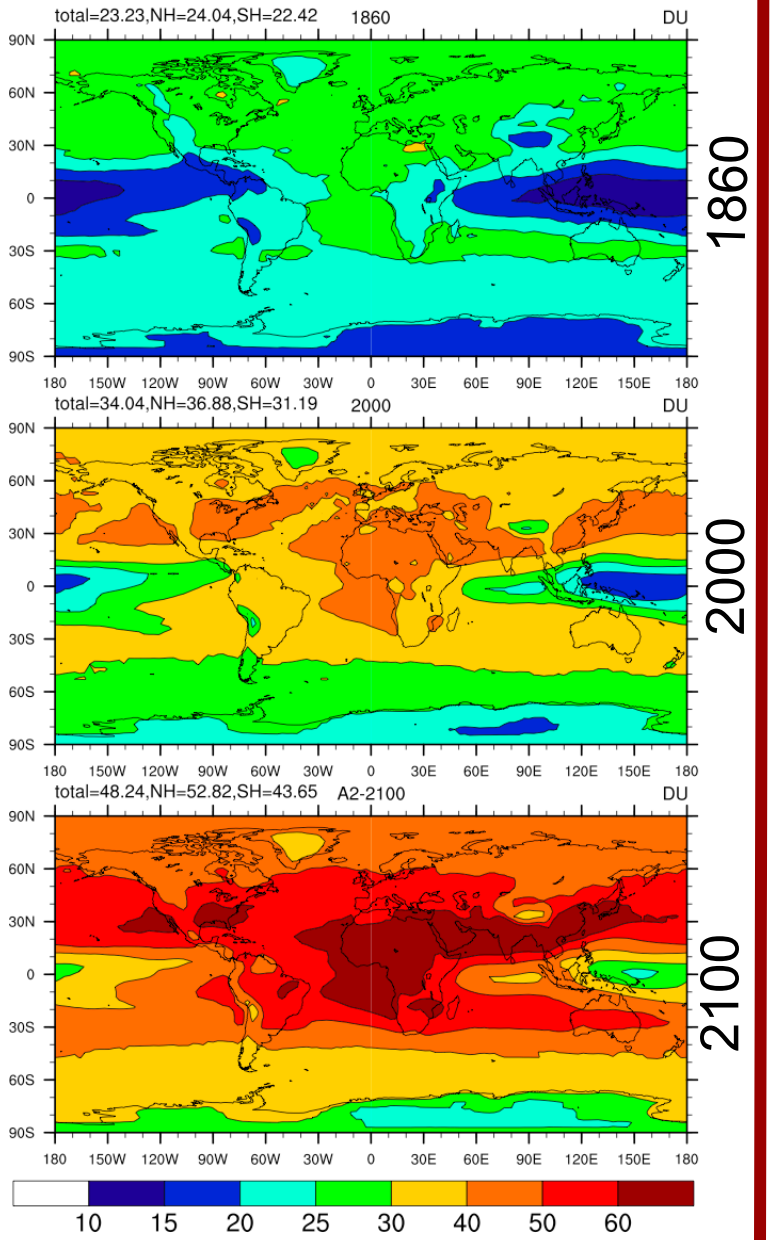
One approach:
Investigate whether GCCM have the right processes:

- Assimilate observations into a GCCM to reproduce current atmosphere.

- Assimilated observations into a chemistry and transport model (CTM).

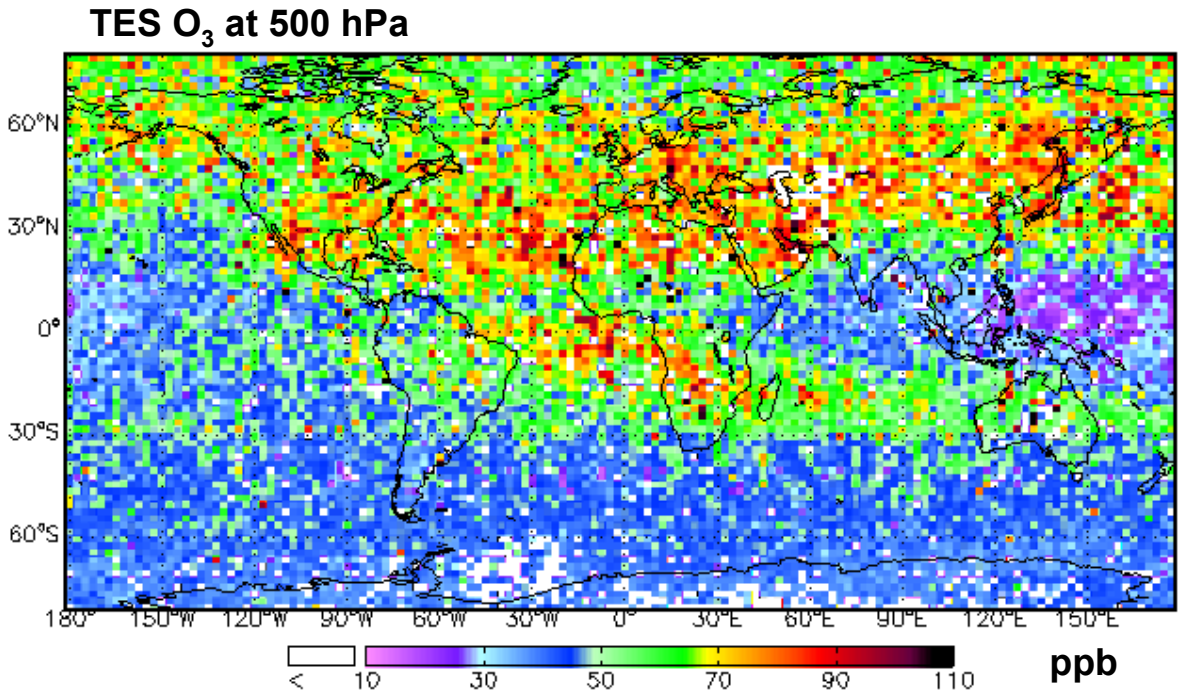
- Evaluate differences between CTM and GCCM.

We must first assess if TES ozone distributions can constrain GCCM and CTM estimates.



L. Horowitz (2006), JGR

TES Global Survey Observations, August 1-31 2006



- Enhanced O_3 abundances from central Asia, across the Middle East, and over the subtropical Atlantic
- High O_3 over the southeastern USA

Tropospheric Models

AM2-Chem

- GCM developed at NOAA GFDL
- 2.0° latitude x 2.5° longitude, 24 vertical levels (top level approx. 10 hPa)
- Chemistry scheme based on MOZART-2 [Horowitz et al., 2003; Tie et al., 2004]
- Stratospheric ozone distribution from HALOE climatology
- Model dynamics constrained by Newtonian nudging to NCEP reanalyses

GEOS-Chem

- Chemical transport model
- 2.0° latitude x 2.5° longitude or 4° latitude x 5° longitude, 55 vertical levels (top level approx. 0.01 hPa)
- Model transport driven by GEOS-4 GMAO analyses
- Linoz parameterization of stratospheric ozone vertical distribution

Chemical Data Assimilation Methodology

Sequential Sub-optimal Kalman filter

$$\hat{\mathbf{x}}_k^a = \mathbf{x}_k^f + \mathbf{K}_k[\mathbf{y}^{\text{obs}} - \mathbf{H}_k\mathbf{x}_k^f]$$

Kalman Gain Matrix: $\mathbf{K}_k = (\mathbf{H}_k\mathbf{P}_k^f\mathbf{H}_k^{\mathrm{T}} + \mathbf{R}_k)^{-1}\mathbf{P}_k^f\mathbf{H}_k^{\mathrm{T}}$

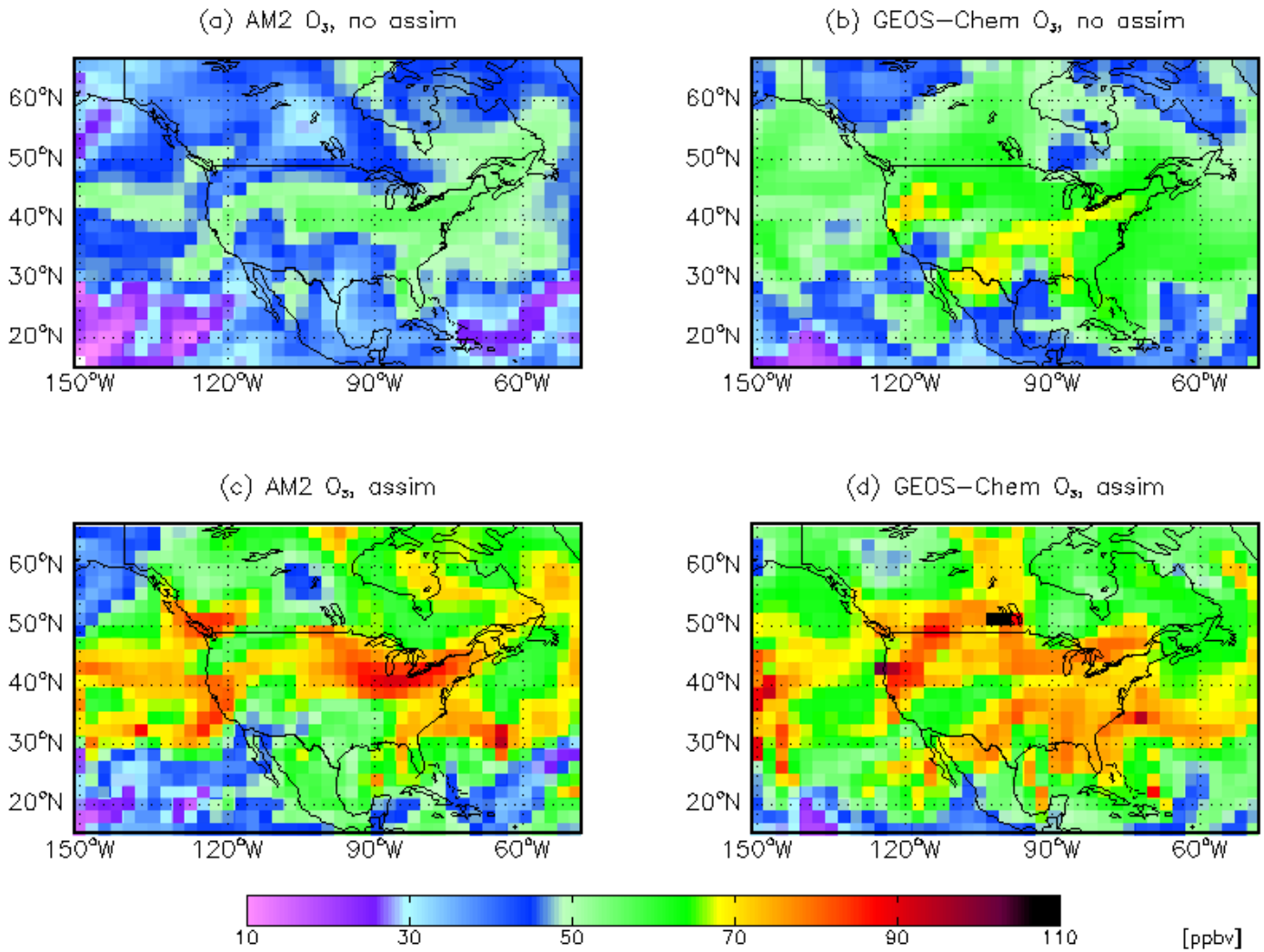
Analysis Error Cov. Matrix: $\mathbf{P}_k^a = (\mathbf{I} - \mathbf{K}_k\mathbf{H}_k)\mathbf{P}_k^f$

- Observation operator (**H**) accounts for TES averaging kernels and a priori profiles
- Analysis error variance transported as a passive tracer

Models and Data Streams

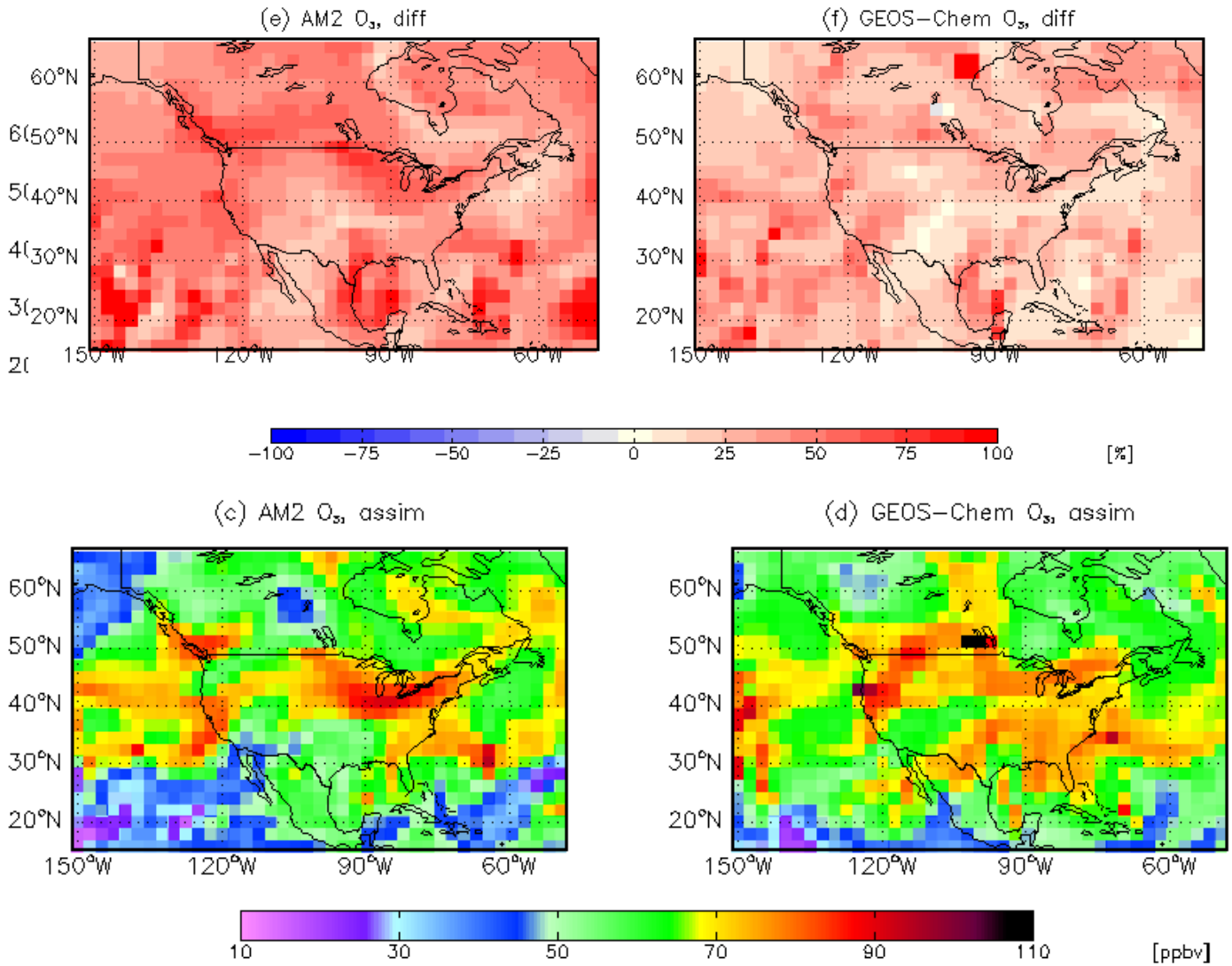
- **GEOS-Chem and AM2 models with full nonlinear tropospheric chemistry**
- **O_3 and CO profile retrievals from TES for July 1 through August 31 2006**
- **6-hour analysis cycle**
- **Assumed forecast error of 20% for CO and 50% for O_3**
- **Neglected horizontal correlations in forecast and observation error covariance matrices**
- **Results presented for 15 August 2006**

Ozone analysis over North America

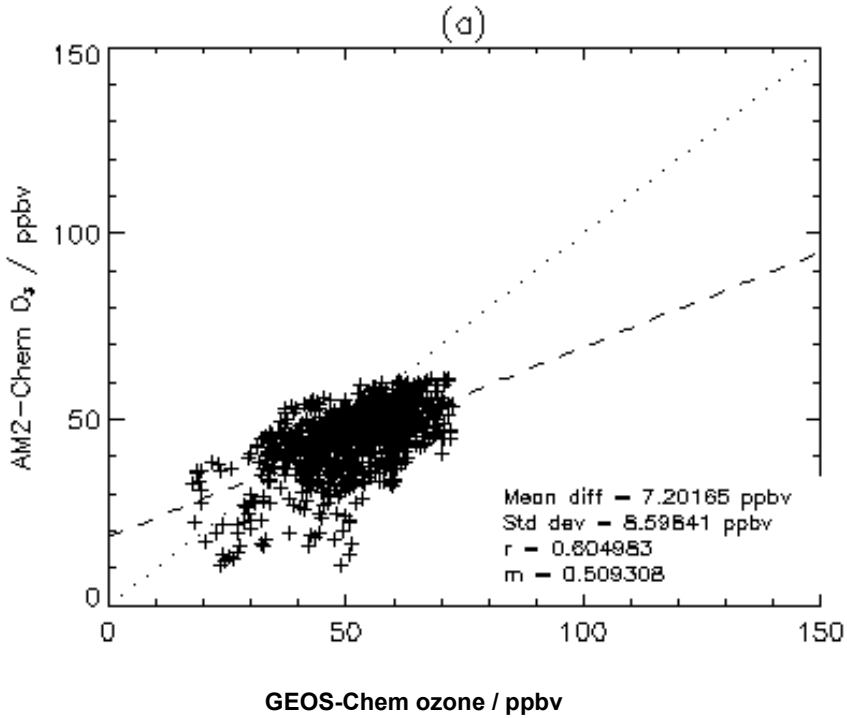


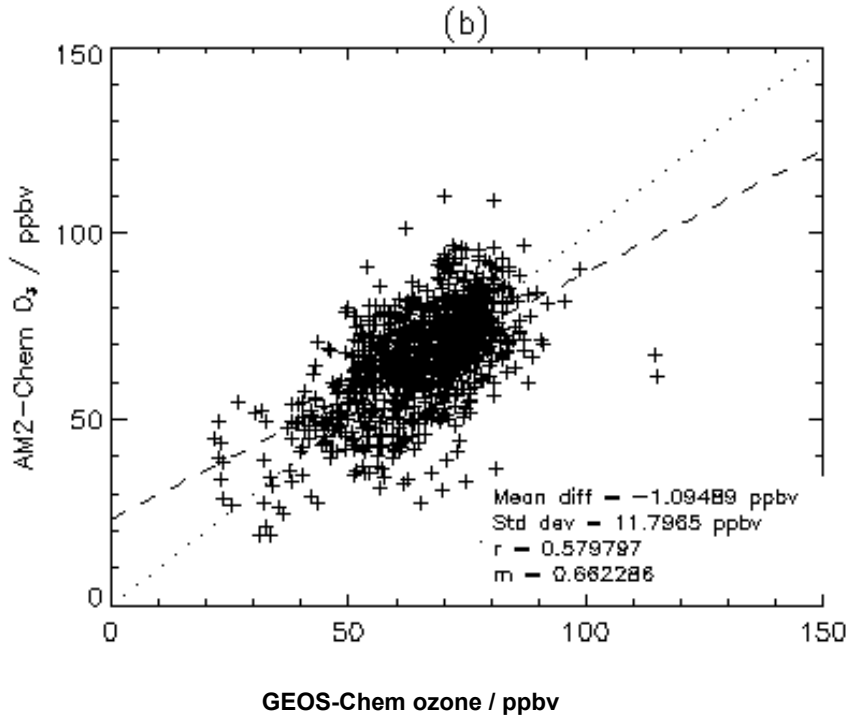
ozone at 5 km, August 15, 2006

Ozone analysis over North America



Impact of TES data over North America and globally

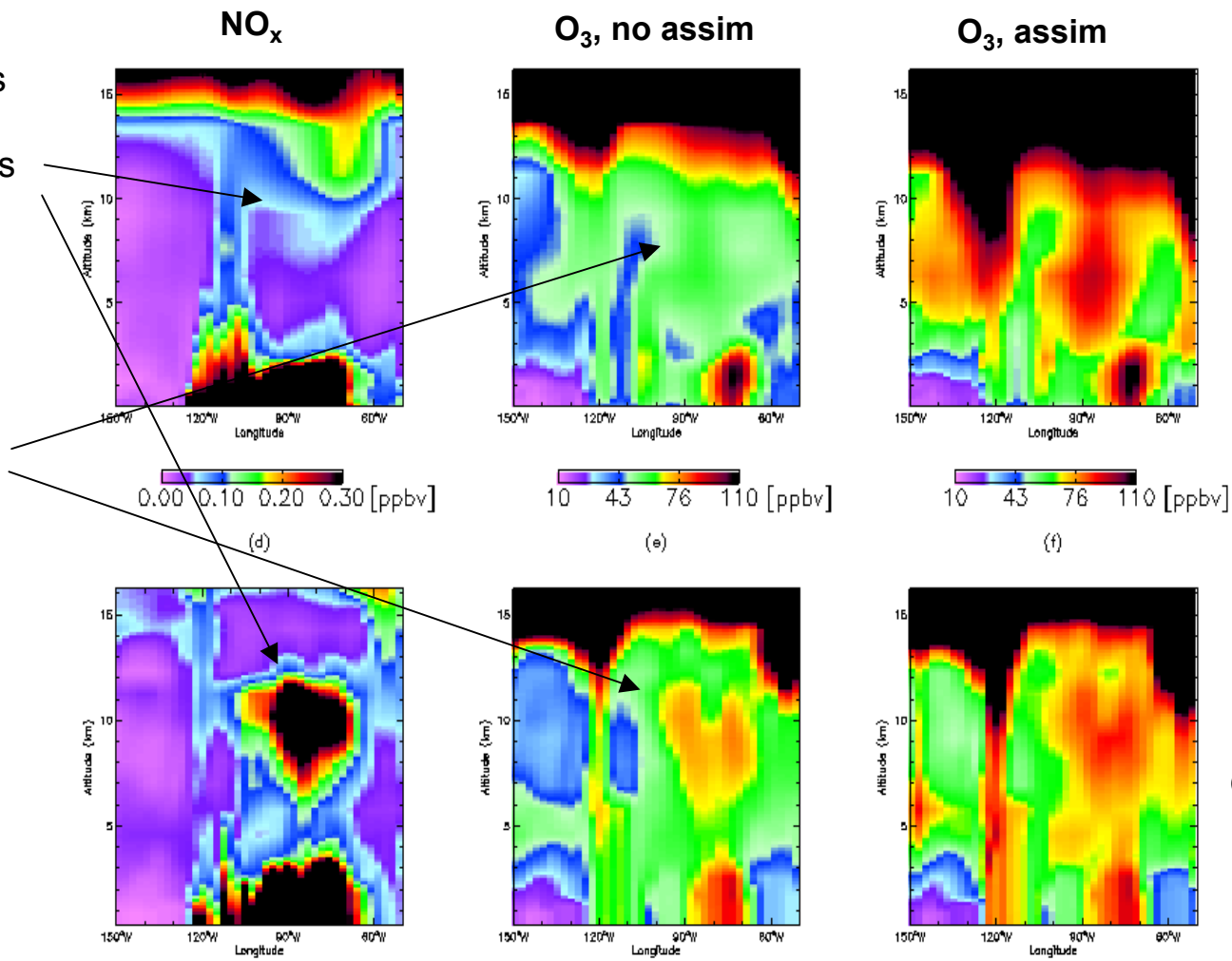




Mean ozone bias between the models over N America is reduced from 7 to -1 ppbv following TES assimilation

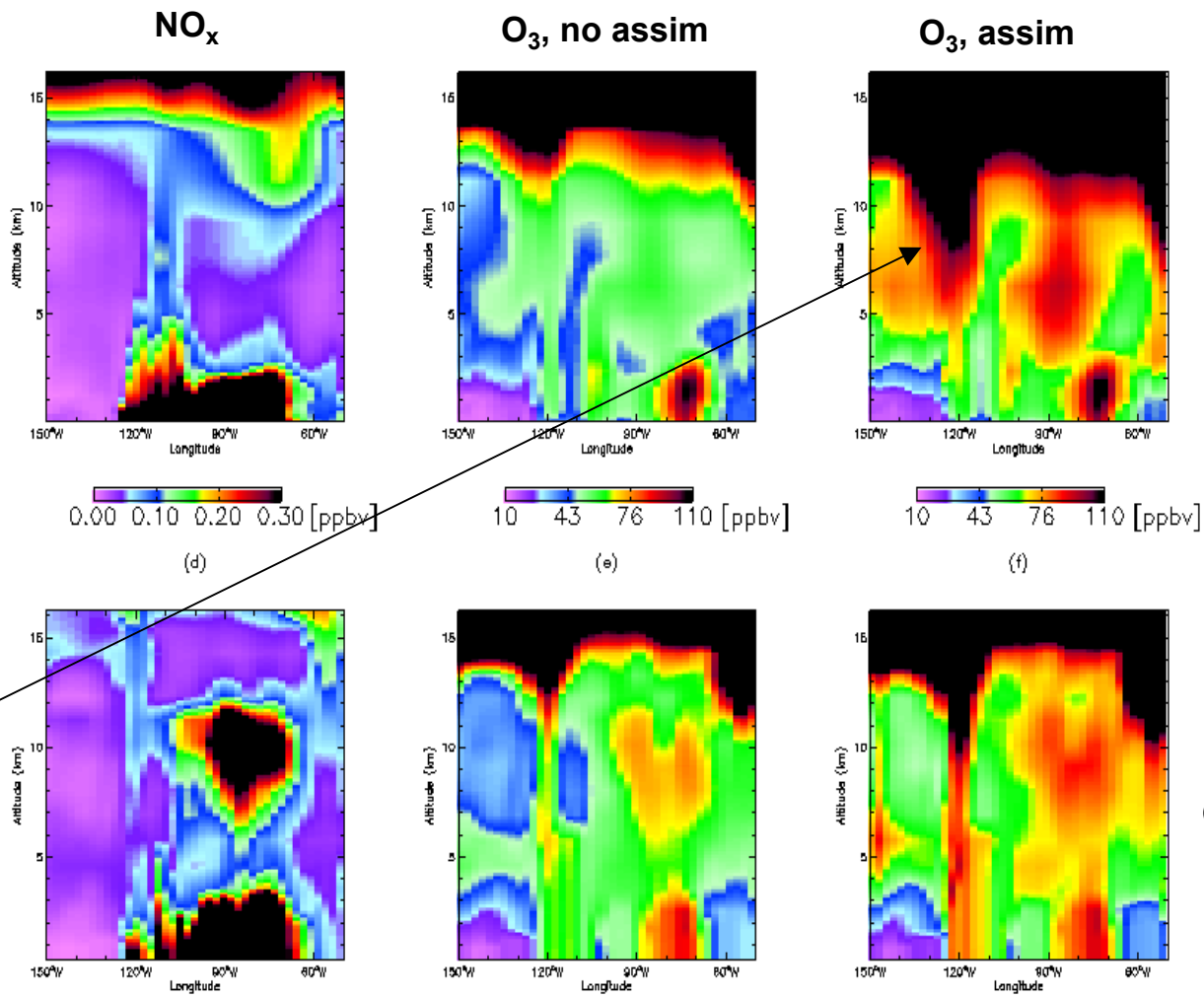
Impact on vertical ozone distribution

Discrepancies in lightning NO_x emissions between the two models leads to differences in UT ozone distribution



Ozone cross-section at 40° N

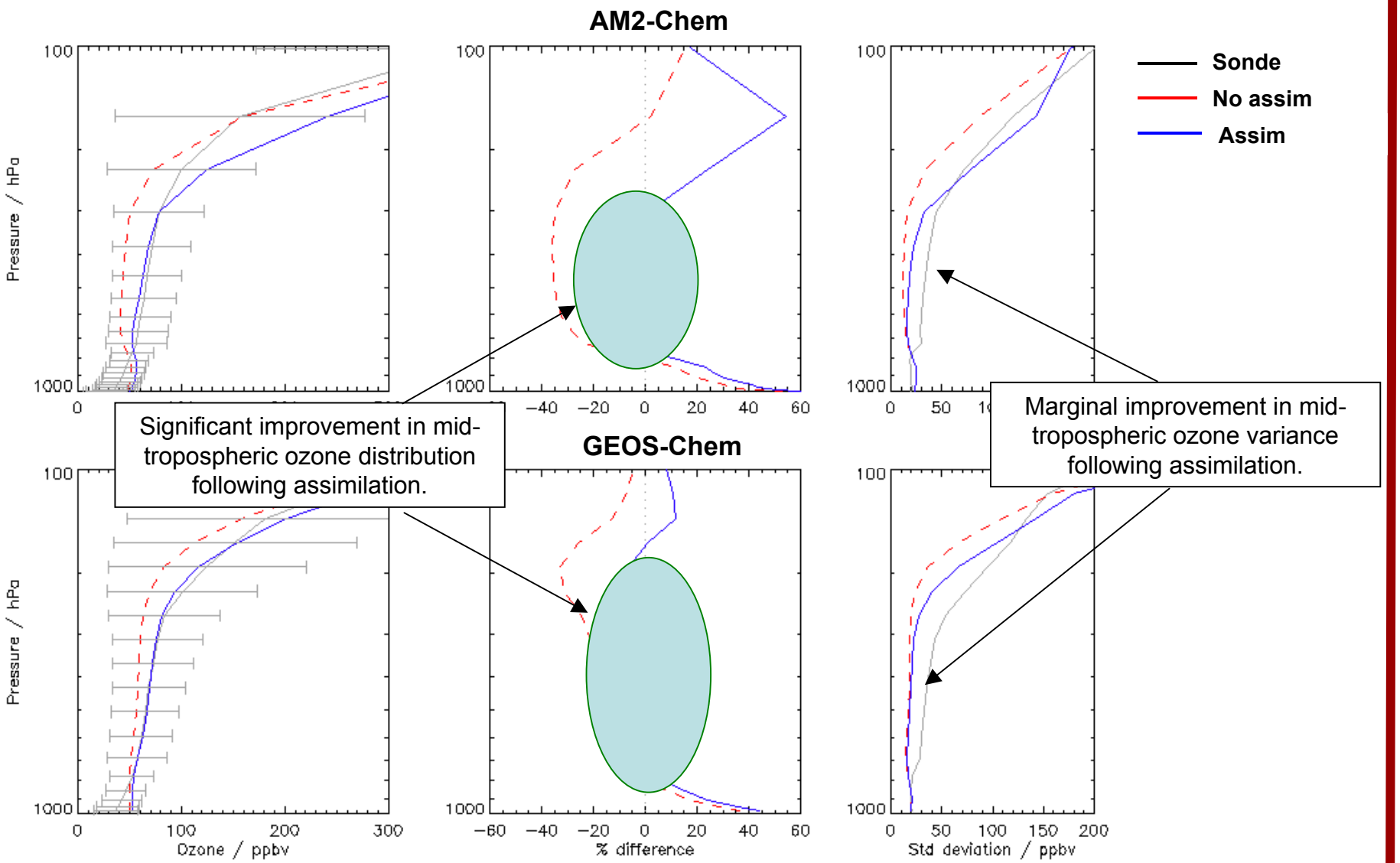
Impact on vertical ozone distribution



Redistribution of ozone "tropopause" (110 ppbv contour) in AM2-Chem reflecting coarse vertical resolution and smoothing of TES retrievals

Ozone cross-section at 40° N

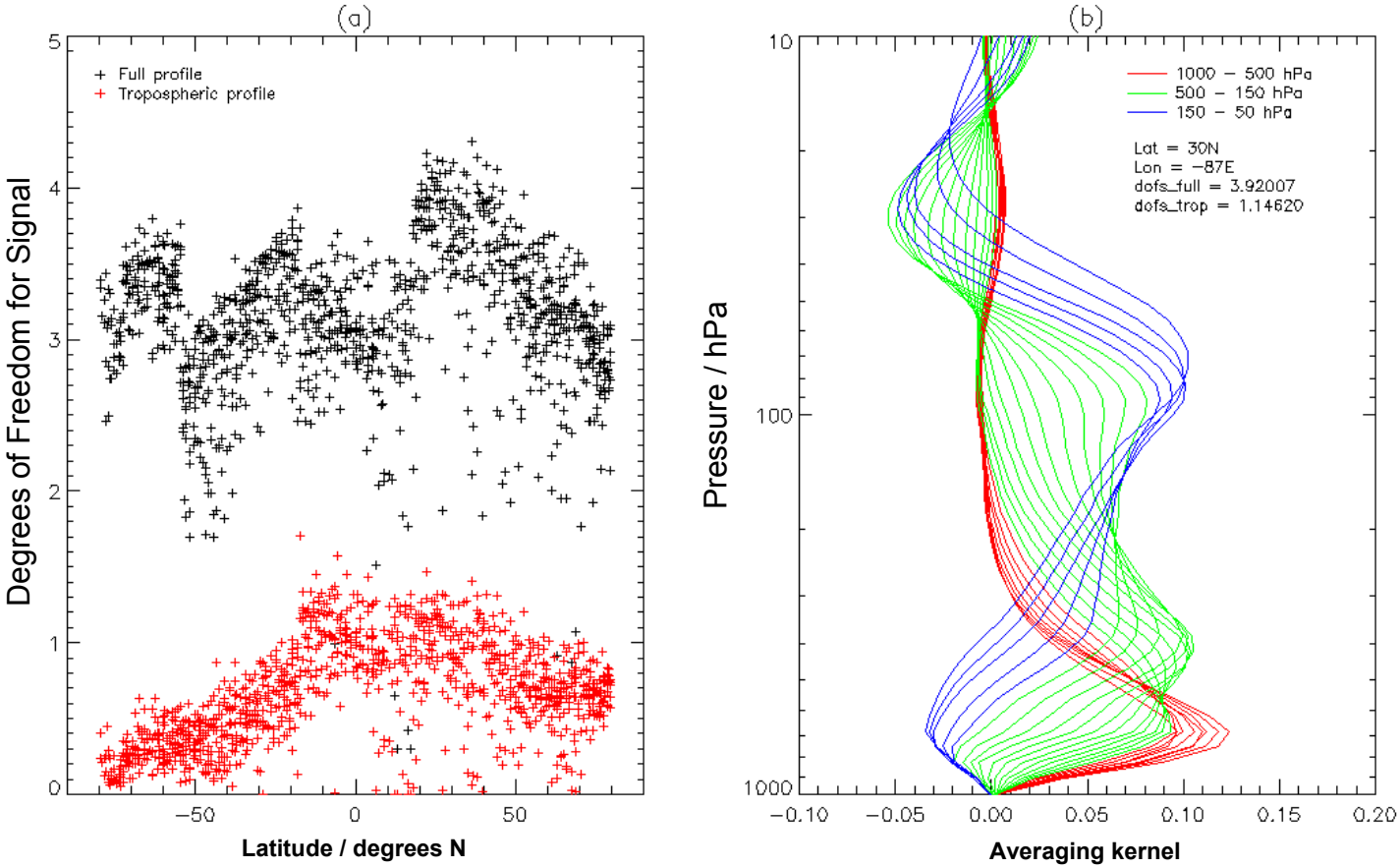
Comparison to IONS ozone sondes



Conclusions

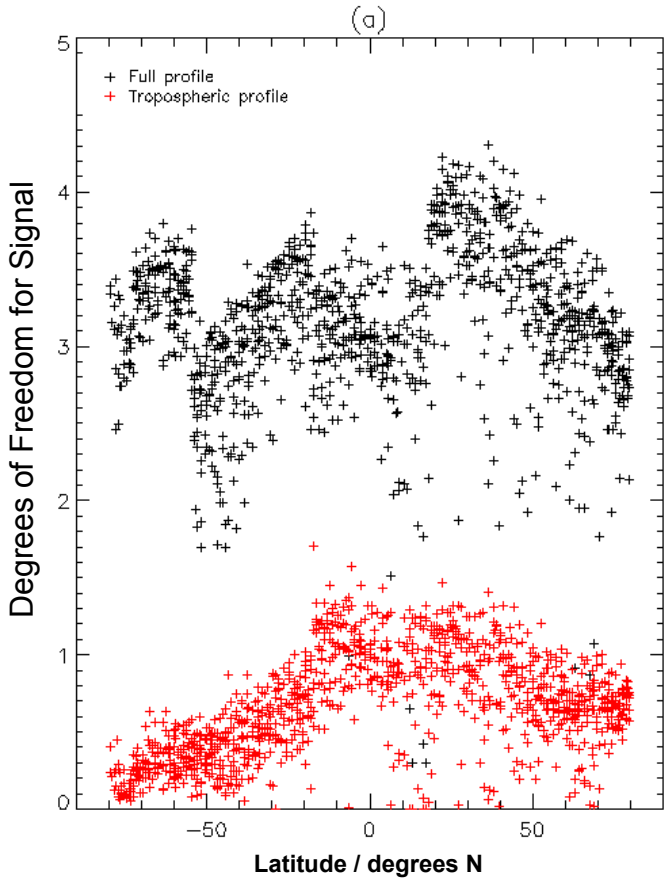
- The TES data have sufficient information to constrain modelled tropospheric ozone distributions
  - Bias between assimilated AM2 and GEOS-Chem < 1ppb.
  - Comparison to IONS ozone sondes in mid-troposphere
    - Less than 10% for AM2
    - Less than 5% for GEOS-Chem
- However, assimilated model fields provided marginal improvement in agreement with ozonesonde variability
  - ozonesonde variability driven by small spatio-temporal scale ("sub-grid") processes not represented in model and not sufficiently sampled by TES data.
- Discrepancies in lightning emissions of NO_x between the two models leads to very different ozone distributions in the upper troposphere
  - "Normalized" radiative forcing ($W/m^2/ppb$) could be overestimated due to lower ozone background.
- Higher vertical resolution is required in both models and data to fully capture steep gradients in the vertical ozone distribution across the UTLS (assimilation of ozone profiles retrieved from limb sounder data such as MLS or HIRDLS will help to better constrain ozone over this region)

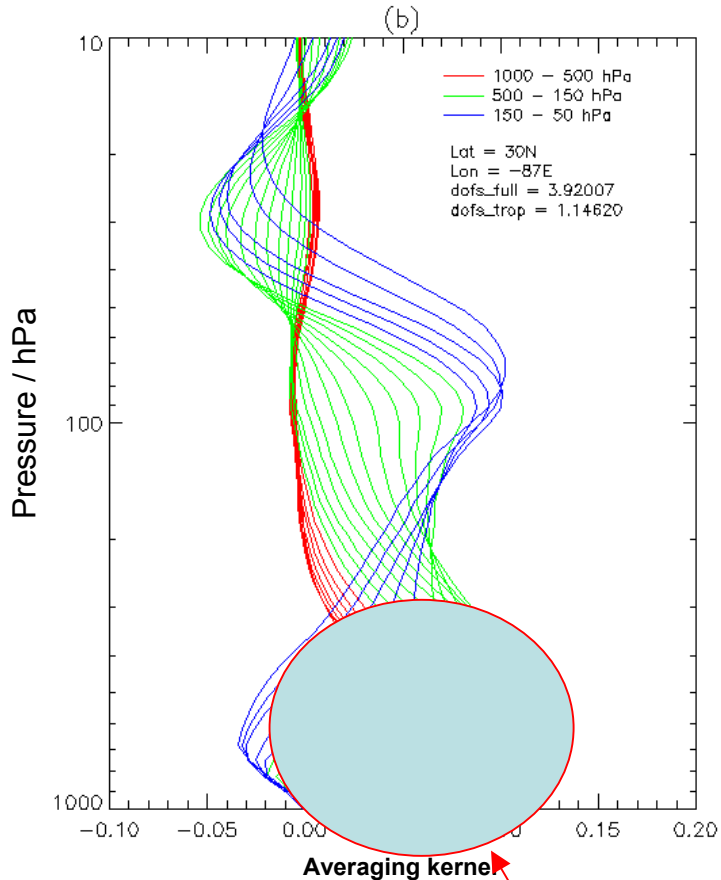
TES ozone profile retrieval characteristics



- The averaging kernel matrix gives the sensitivity of the retrieved profile to the true state of the atmosphere
- The Degrees of Freedom for Signal (DOFS) (the trace, or summation over the rows of the averaging kernel matrix) give a measure of how many independent pieces of information are retrieved

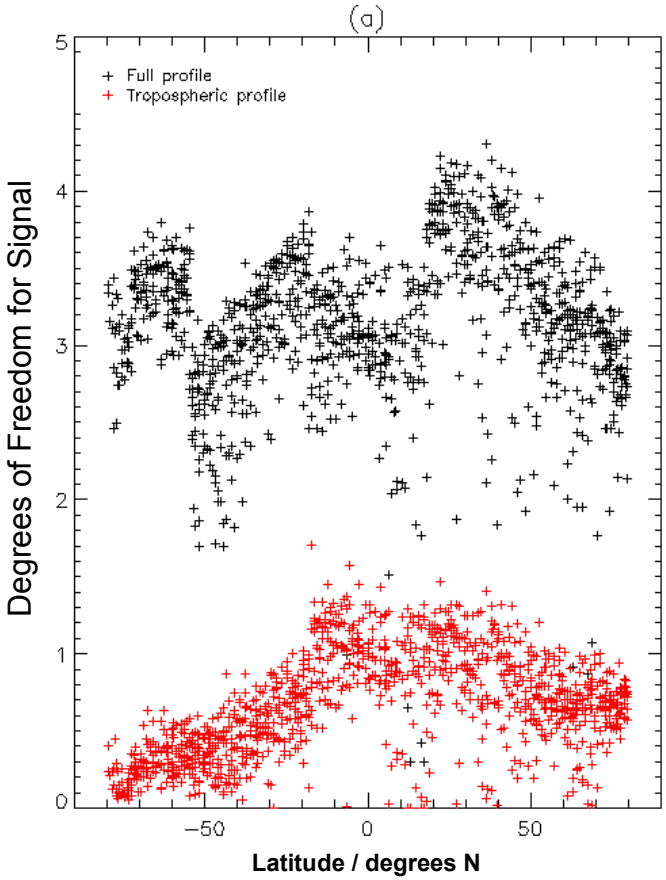
TES ozone profile retrieval characteristics

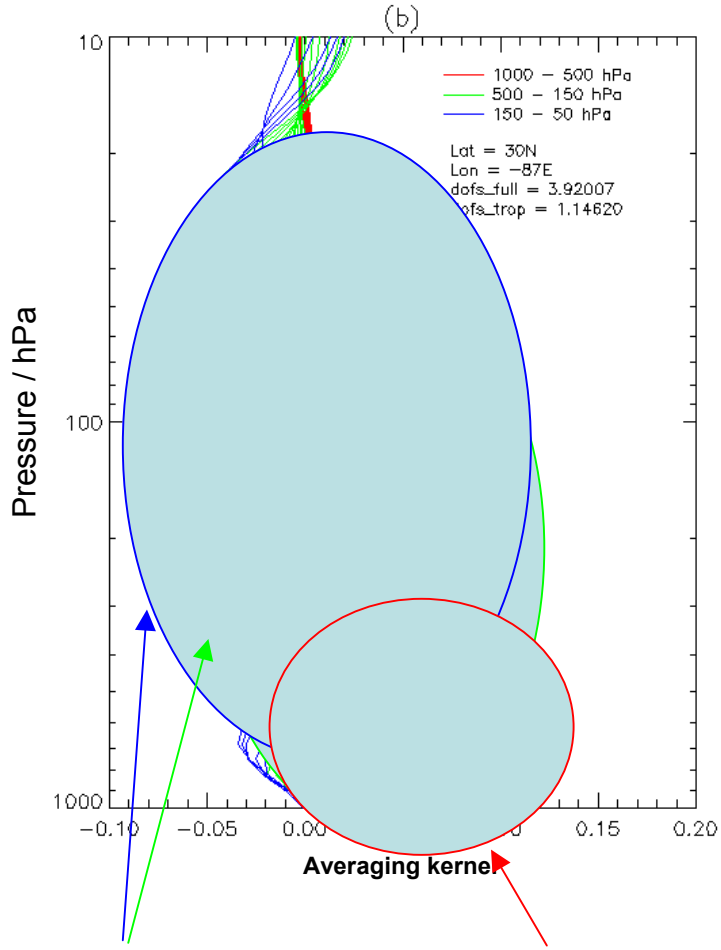




Sensitivity in mid- to lower troposphere

TES ozone profile retrieval characteristics

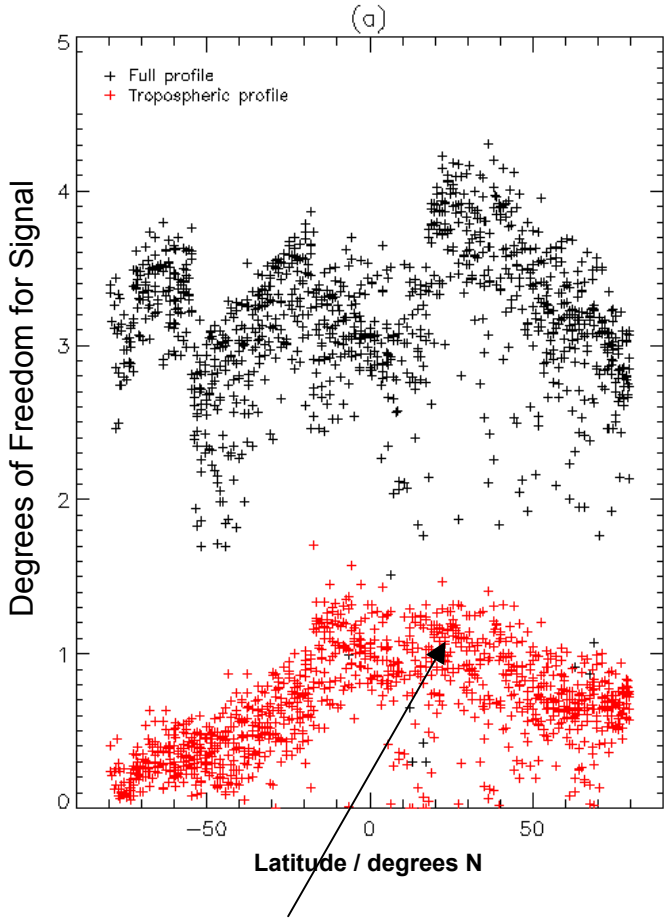


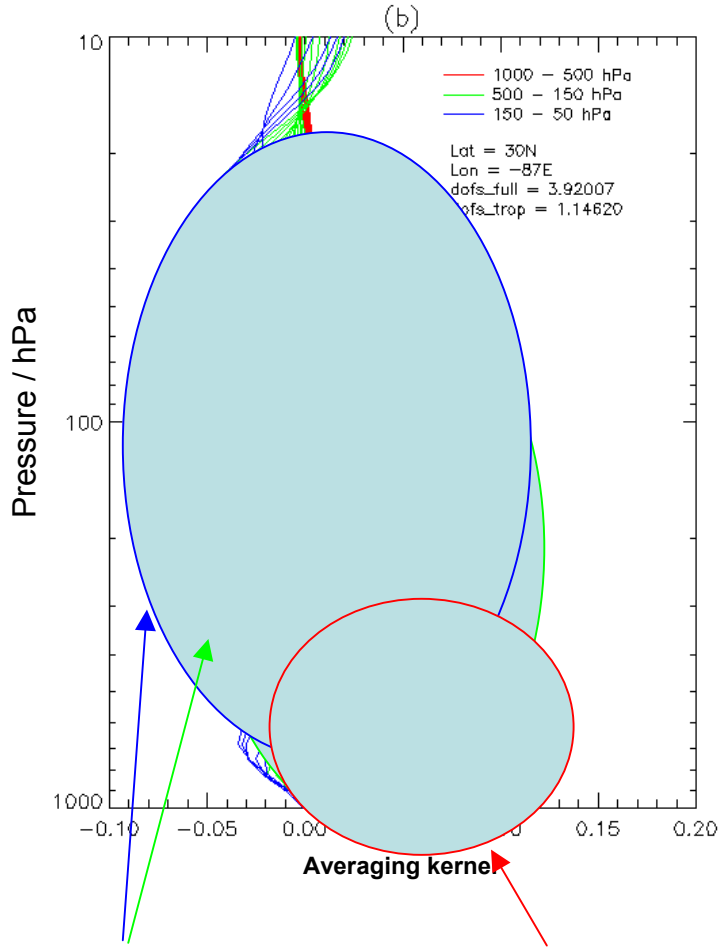


Smoothing of information across the tropopause

Sensitivity in mid- to lower troposphere

TES ozone profile retrieval characteristics



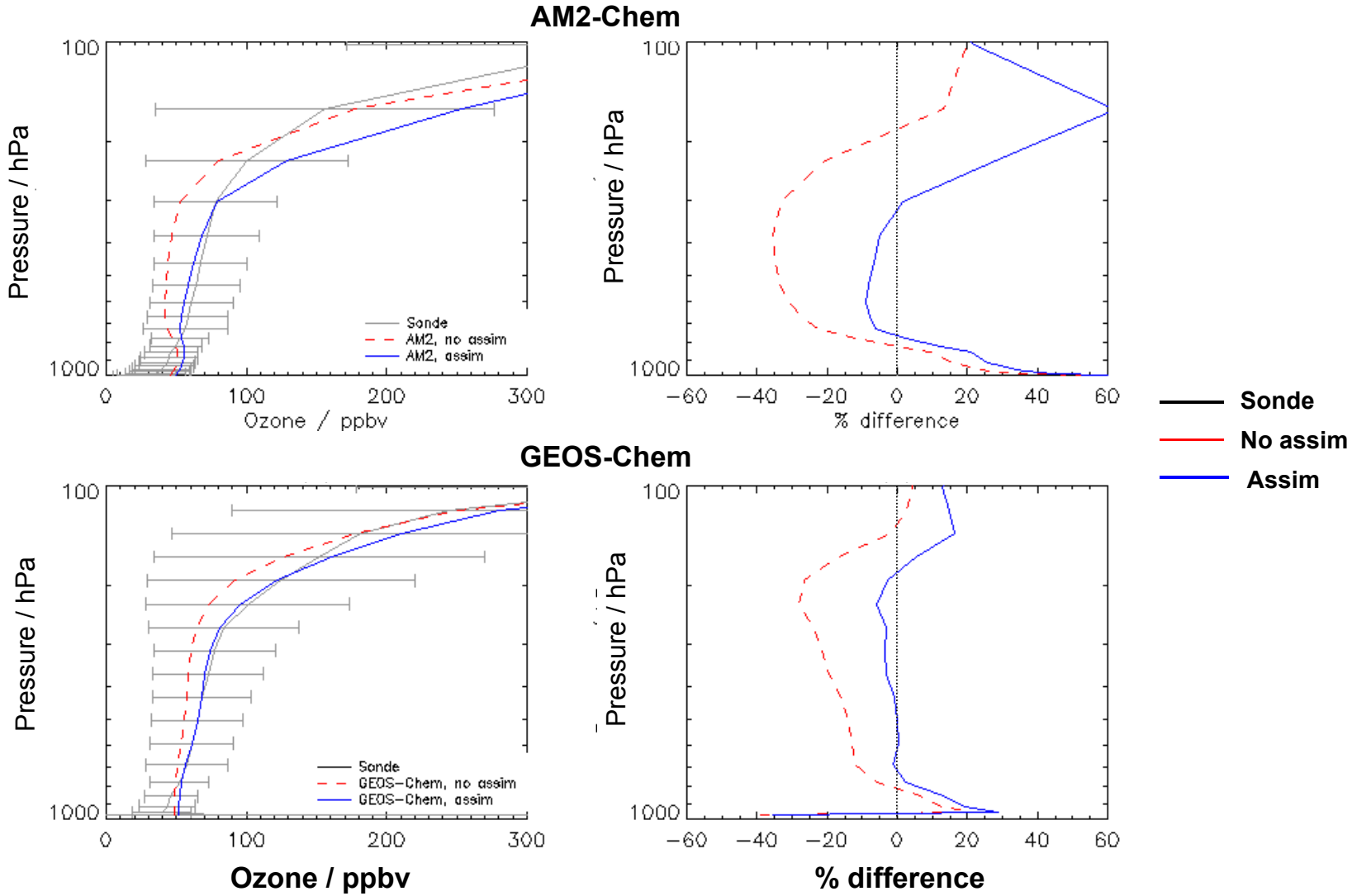


More than 1 piece of independent information in NH troposphere (c.f. 3-4 for full profile retrieval)

Smoothing of information across the tropopause

Sensitivity in mid- to lower troposphere

Comparison to IONS-06 ozonesonde profiles, August 2006



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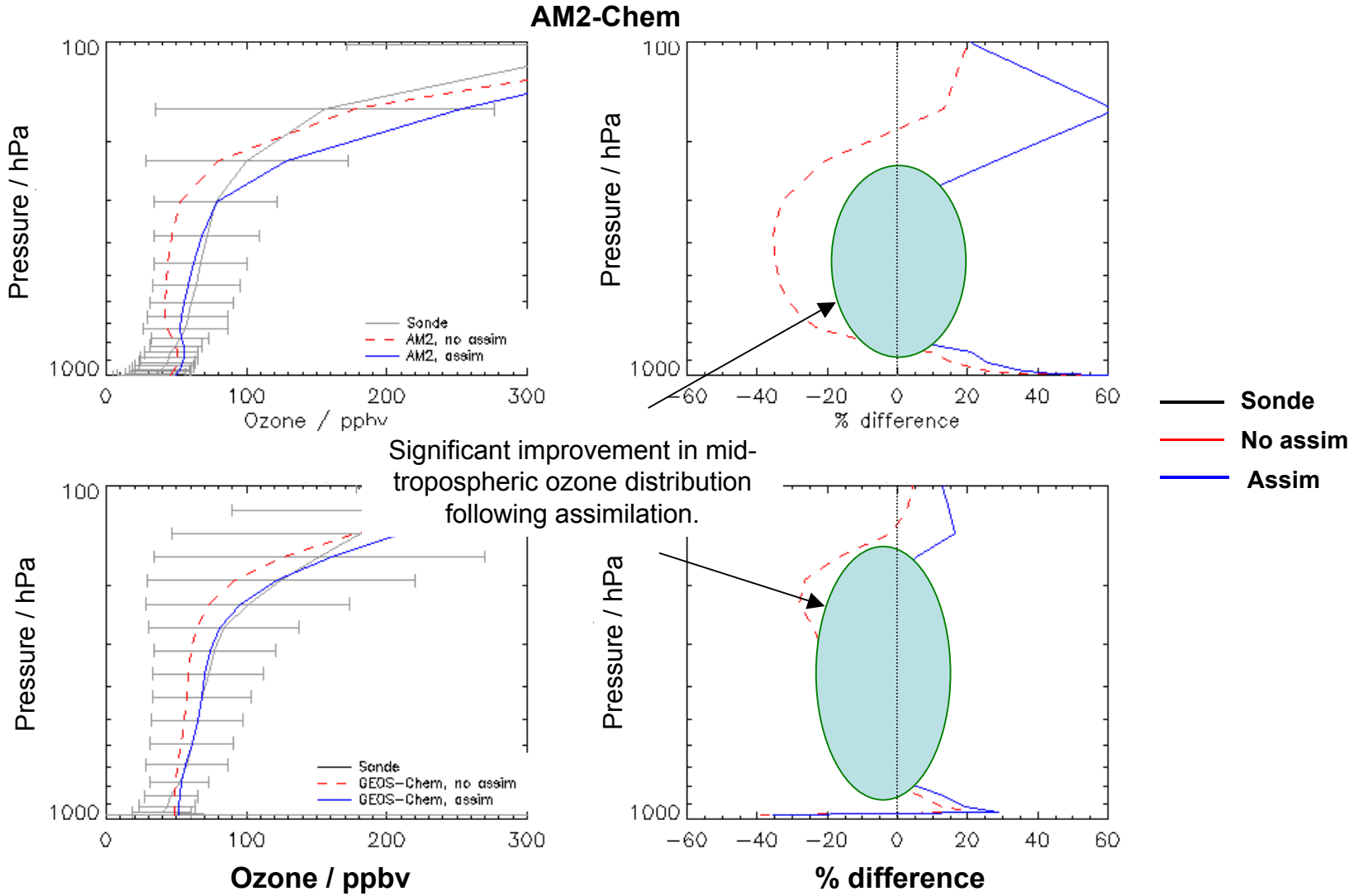
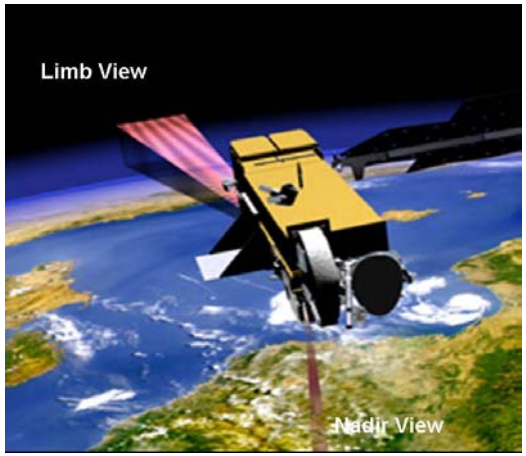


Tropospheric Emission Spectrometer

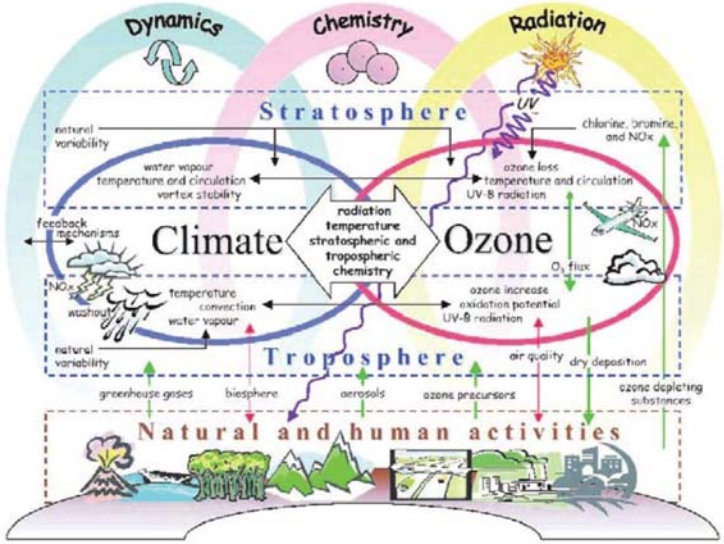


- One of four instruments on the NASA EOS Aura platform, launched July 14 2004
- Sun-synchronous orbit as part of the A-train, with 1.43pm ascending node
- Infrared Fourier transform spectrometer with spectral range from 650-3050 cm^{-1} at 0.1 cm^{-1} spectral resolution
- Nadir footprint = 8 km x 5 km
- Observations spaced about 5^{o} along orbit track
- Orbit repeats every 16 days
- Data products include tropospheric ozone, carbon monoxide, methane, water vapour, and temperature

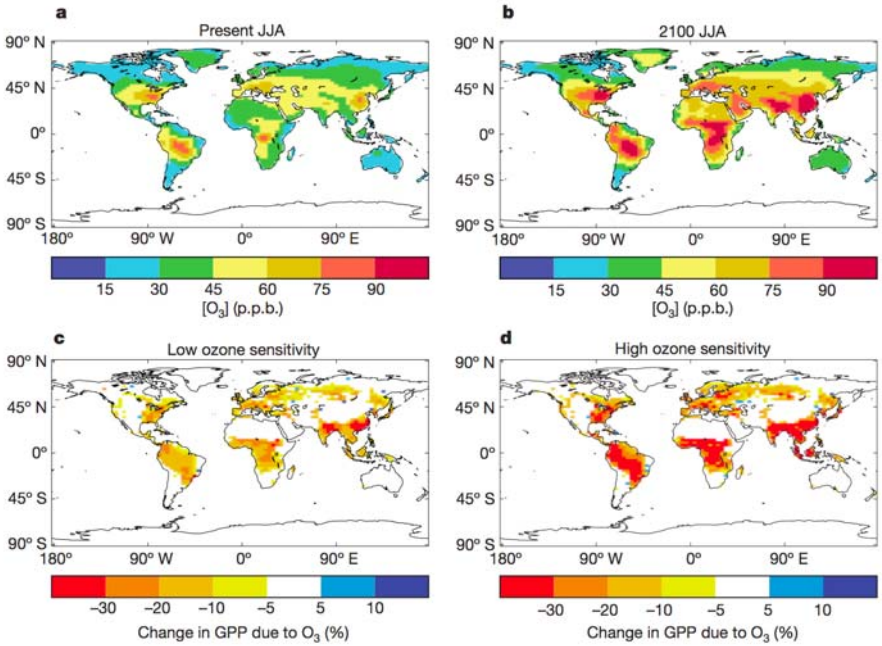
Objective: Integrate satellite data to better quantify the budget of tropospheric O_3

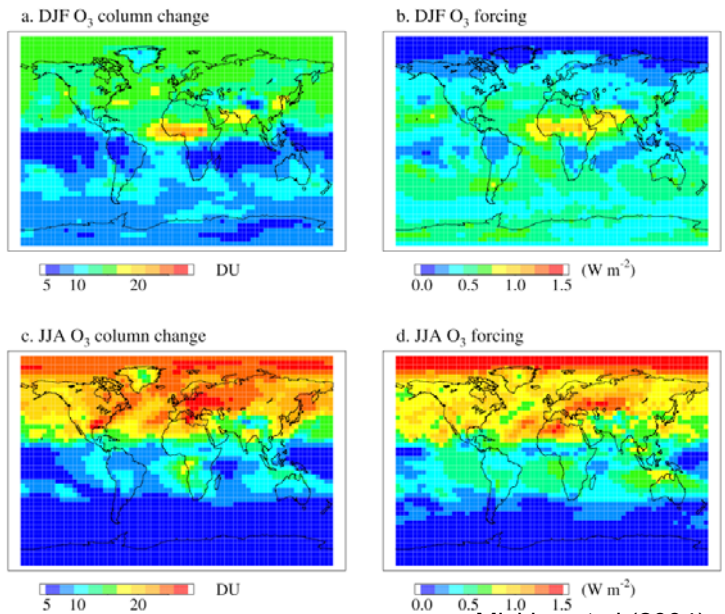
Role of ozone in chemistry-climate coupling

- Ozone has both significant direct and indirect effects on radiative forcing while playing a key role in air quality
- How will ozone amplify or dampen future climate change?
- How will climate change effect future air quality?



Sitch et al,(2007), *Nature*





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